THE EFFECT OF FORCE AND TUBE DIAMETER ON THE VELOCITY AND HEIGHT OF A PNEUMATIC MISSILE

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This experiment tests the effects of force and tube diameter on the height and velocity of a pneumatic missile. A manual foot pump as the source of air pressure and small plastic adapters with holes drilled in the center to regulate the tube diameter. Different forces were dropped on the foot pump to regulate the force applied. From the results, found that there was not an interaction between tube diameter and force on the height or velocity of the missile. To conclude, it was found that the large force and the smallest tube diameter produced the largest height and velocity.

INTRODUCTION

Most people have no idea what pneumatics is by definition, but they do know about air pressure. They know that jackhammers are annoying in the morning, or how being shot with a Nerf gun can hurt. What many people do not know is that both of these things, as well as many others, all work by pneumatics. For our project, we used a pneumatic missile, and tested how changing the force and the tube diameter to let air through affected the height and velocity of the missile.

Sounds complicated right? The force applied to our missile was regulated by dropping different weights onto a foot pump, which shot the missile into the air, much like many Nerf toys. The tube diameter was regulated by screwing different adapters with different size holes into the launcher right beneath the missile. We used devices called photogates to measure the velocity of the missile as it shot into the air. Photogates work much like the radar detectors in Ohio and many other states that the police use to tell if you are speeding. (Not that you would ever do that, right?)

One thing that may help you understand pneumatics and air pressure is Bernoulli's Principle. Bernoulli's Principle states that as the velocity of a fluid, or in this case air, increases, its pressure decreases ("Bernoulli's Principle"). Think of a large tube that flows into a smaller one. Through the wider part of the tube, the air flows at a slower rate but exerts more pressure on the tube. As the air flows through the thinner part of the tube, the air flows at a quicker rate and does not have enough time to apply pressure to the tube as it passes through.

Bernoulli's Principle works in this experiment because changing the area that the air had to flow through affected the height and velocity of the missile.

Another thing that was used in this experiment was the definition of force and an explanation of Newton's second law. Newton's second law states that: "When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force" (Serway). In other words, the mass of the object times the acceleration of the object equals the force one applied on the object. This law was used because of the force we were applying to the foot pump, which in turn made the missile launch into the air.

We regulated the force applied to the missile launcher by using different forces in the form of weights. The tube diameter came in three sizes, small hole, medium hole and no adapter. Our project utilized Bernoulli's Principle and utilized research in the field of pneumatics.

REVIEW OF LITERATURE

Nerf guns; everyone has shot them; everyone has been shot by them. Nerf guns use air to power their not-so-soft projectiles through the air; this power is created by pneumatics. Pneumatics is the study of mechanical properties of air and other gases ("Pneumatics"). Pneumatic systems work by compressing air and then using that compressed air as a way to move an object. To further explain how pneumatic systems and tools work, one must have a basic understanding of velocity and Bernoulli's Principle of pressure.

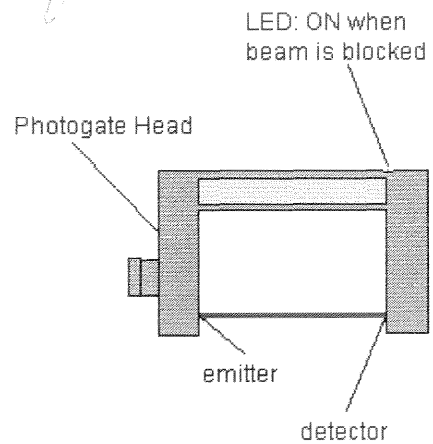
Velocity, by definition, is a physical quantity describing both the speed of an object and the direction of its motion ("Velocity"). For example, if one throws a ball north at a velocity of 5 meters per second, then the object has a velocity of 5 meters per second, or $^{m}/_{s}$, to the north. Velocity is different than speed because speed has no direction. When someone gives a rate at which an object is moving without mentioning its direction, then the person has given the speed and not the velocity.

Bernoulli's Principle of fluid dynamics was discovered by an 18^{th} century Swiss scientist named Daniel Bernoulli. He stated that as the velocity of a fluid increases, its pressure decreases ("Bernoulli's Principle"). A fluid is defined by having the ability to flow, thus it is applied to both liquids and gases (Sootin 84). As a fluid, air in this situation, flows through a pipe that either narrows or widens, then the velocity and pressure of the fluid will vary. As the pipe narrows, the fluid will flow more quickly. Bernoulli's Principle tells us that as the fluid flows more

quickly through the narrow sections, the pressure actually decreases rather than increases (Mitchell).

In the 1730's, while writing his great work Hydrodynamica, Daniel Bernoulli discovered this principle. *Hydrodynamica* tells for the first time, the correct analysis of how water flows through a hole in a container. He based this analysis off the principle of the conservation of energy, which states that energy cannot be created nor destroyed; it is merely transferred from object to object ("Daniel Bernoulli"). Bernoulli published an equation to find the pressure of the fluid flowing through a pipe.

Force is measured in Newtons; the symbol for this unit of measure is the capital letter, N. The Newton was discovered by Sir Isaac Newton, who discovered three important laws, many of which had to do with motion and gravity. His second law states that: "When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force". Another way to look at this is that the amount of force one applies to an object is equal to the object's mass times the acceleration of the object. The formula that accompanies this law is "F=ma", or force equals mass times acceleration (Serway). In this experiment, we had weights that were dropped on our setup to launch the missile. These weights were measured in kilograms, not Newtons. So to convert, we multiplied their weight by the acceleration due to gravity because they were freefalling objects. The acceleration due to gravity is 9.81 $^{m}/_{s}{}^{2}$.



Photogates are devices used to record the velocity of an object as it passes through its two gates. A Photogate works by sending out a light source, in the form of the beam, which travels from the emitter to the detector on the other side. In our experiment, we used the Photogates in sets of two. They measure the velocity of an object from where it passes from one Photogate to the next. The timer starts from when the first beams is blocked by the object and the timer ends when it passes through the next Photogate. For example, if someone wants to measure the velocity of a Hot Wheels© car, then they would put two Photogates on the track so that when the car goes down the track, it breaks the laser beam ("Photogates").

For many years, pneumatics has been a way to inexpensively power devices such as jackhammers and nail guns, while keeping the machines quiet compared to their fuel-powered counterparts. They are used in daily life to paint cars, pump tires or paint with an airbrush ("Pneumatic Tool"). One reason for this experiment was to get a better understanding of pneumatic tools and how they work. The reason we chose a missile was that it was a fun and interesting way to study air pressure and how changes in it affect the launch of the missile.

A Design of Experiment, also known as a DOE, is a way to analyze data and determine whether the predictor variables, the item you are using to test such as tube diameter or force, have an effect on your response variable, the

data you are looking for such as velocity or height. DOE's also test whether the predictor variables interact and change the effect of your response variable. A DOE is a statistical analysis.

Our experiment came from the book, Backyard Ballistics. We chose this experiment and modified it to fit our needs. Although we could not find results of the same experiment, we did have a manual with possible problems that could occur in our experiment. However, the book does not have data or the problem for our experiment, so we were unable to compare our data to previously published results.

In summation, our missile was made in a pneumatic form. We studied the effect of the diameter of the launching tube and the effect of the force on the foot pump on the missile. We recorded the velocity of the missile through the Photogates and the height of the missile using meter sticks taped together. Finally, we used statistics to analyze our data.

PROBLEM STATEMENT

Problem:

To examine the effect of changing the diameter of the tubing and the force initially applied to the pump on the velocity of the missile and to examine the effect that the tube diameter and force applied on the pump have on the height of the missile.

Hypothesis:

If we change the diameter of the tube and the force applied to the pump, then the smallest tube diameter and the largest force will give the missile the largest velocity and launch the missile the highest in the air.

Data Measured:

We are measuring the height and the velocity of the missile. The independent variables are the three different sizes of tubing diameters and the different forces applied to the pump. The dependant variables are the velocity of the missile as it is launched and the height of the missile. The velocity will be measured utilizing Photogates attached to a wooden dowel on the base of the launcher. We will be doing 15 trials of each factor; thus launching the rocket 105 times.

EXPERIMENTAL DESIGN

Materials:

- (1)- 12-inch x 10-inch x ½-inch piece of particle board (mark "A")
- (1)- 18-inch x 16-inch x ½-inch piece of particle board (mark "B")
- (2)- 2-inch x 2-inch x 8-inch wooden pillars (mark "1" and "2")
- (2)- 2-inch x 2-inch x 10-inch wooden pillars (mark "3" and "4")
- Nails- assorted lengths
- Phillips screws- assorted lengths
- Electrical tape
- Hammer
- Philips screwdriver
- File
- Drill
- Scissors
- Threader
- Pliers
- Sand paper
- (1)- 18-inch length of schedule-40 PVC pipe
  - ½ -inch diameter
- (1)- ½-inch x ½-inch x ½-inch PVC tee joint
  - Two ends smooth, middle end threaded
- (1)- brass hose adapter
- (1)- PVC end cap
- Air foot pump
- Pink foam in 2-inch x 2-inch x 2-inch block
- (1)- 3-foot dowel rod ½-inch thick
- (1)- 12-inch x 12-inch x 2-inch block of wood
- (1)- 8-inch x 1-inch hard, clear plastic tubing
- (1)- ½-inch diameter wooden dowel 8-inches long
- Computer with Logger Pro
- TI-83+ Calculator
- (2)-Photogates with metal connector rod
- 5.5kg weight (53.96 N)
- 8.6kg weight (84.37 N)
- 11.6kg weight (133.80 N)

Preliminary Procedures:

Making the Launcher

1. Drill hole into the middle of the 12-inch x 12-inch block big enough to fit PVC end cap inside.

2. Cut a 4-inch piece off the PVC pipe. Cover one end of the pipe with the PVC cap and push the other end into the tee joint.

3. Cut the 18-inch pipe into a 12-inch pipe and attach to the tee joint. Use a threader to make threads ½-inch deep into the top of the pipe. Use the pliers as extra leverage.

4. Put brass adapter onto middle threaded part of tee joint.

5. Use the electrical tape around the PVC cap and the pipe to insure a snug fit in the hole of the wooden block.

6. Attach Photogates to metal rod at opposite ends. Then attach the metal rod to wooden dowel with electrical tape.

7. Drill another hole in the base so that the missile will be able to go through the Photogates in a vertical fashion. Glue the dowel into the base.

8. Stretch out the flexible plastic tubing that comes with the foot pump and attach to the hose adapter.

8. Attach pump to flexible hose.

9. Refer to Figure 1.

Making the Missile

1. Sculpt the pink foam into a subtle nose cone using sand paper. Make sure the nose cone has an extra length to fit into the clear plastic tubing.

2. Push the nose cone into the tubing. Cover the nose cone with electrical tape to ensure strength and a tight fit.

Making the Foot Pump Holder

1. Take the largest piece of particleboard B and mark where wood block 3 will lay down. This will hold the pump in place while the force is dropped on the foot pump.

2. Pre-drill holes into the particleboard B and wood block 3 and attach to the board using screws. Make sure the screws do not go all the way through the pillar.

3. Look at board B and place pillars 1 and 2 on either side of the wood block 3. Trace around pillars 1 and 2.

4. Pre-drill holes through the center of the traced boxes. Drill holes 1-inch deep into pillars 1 and 2.

5. Pre-drill holes horizontally through the pillars 1 and 2 approximately 1 ½ inches from the top. This will allow nails to go through and rotate along the lever.

6. Screw pillars 1 and 2 into the particleboard.

7. Take particleboard A and the final wooden block, 4. Pre-drill holes in the ends of wooden block 4 so that they line up with the horizontal holes in pillars 1 and 2.

8. Pre-drill holes in particleboard A and wooden block 4. Screw particleboard A to the final wooden pillar 4.

9. Push nails through the vertically standing wooden pillars 1 and 2 and into the holes in wooden block 4.

10. Put the pump underneath the flap and push the tube leading to the launcher underneath the flap.

11. Refer to Figures 2 and 3 for additional visuals.

Procedures:

1. Using Logger Pro set up the computer to the Photogates.

2. Place missile on the floor so that the missile will go through the Photogates when launched.

3. Randomize trials using random integer on TI-83+.

4. Place the rocket over the launch tube.

5. With weight according to the trial being run, drop the force from 2 feet onto the foot pump.

6. Using meter sticks attached to the wall, mark the maximum height the missile reaches. Record the height on a separate data table.

7. Using Logger Pro, have the other partner record the velocity of the missile.

8. Run 15 trials of each factor; thus launching the rocket 105 times and record the data.

Diagrams:

Figure 1. Missile Diagram

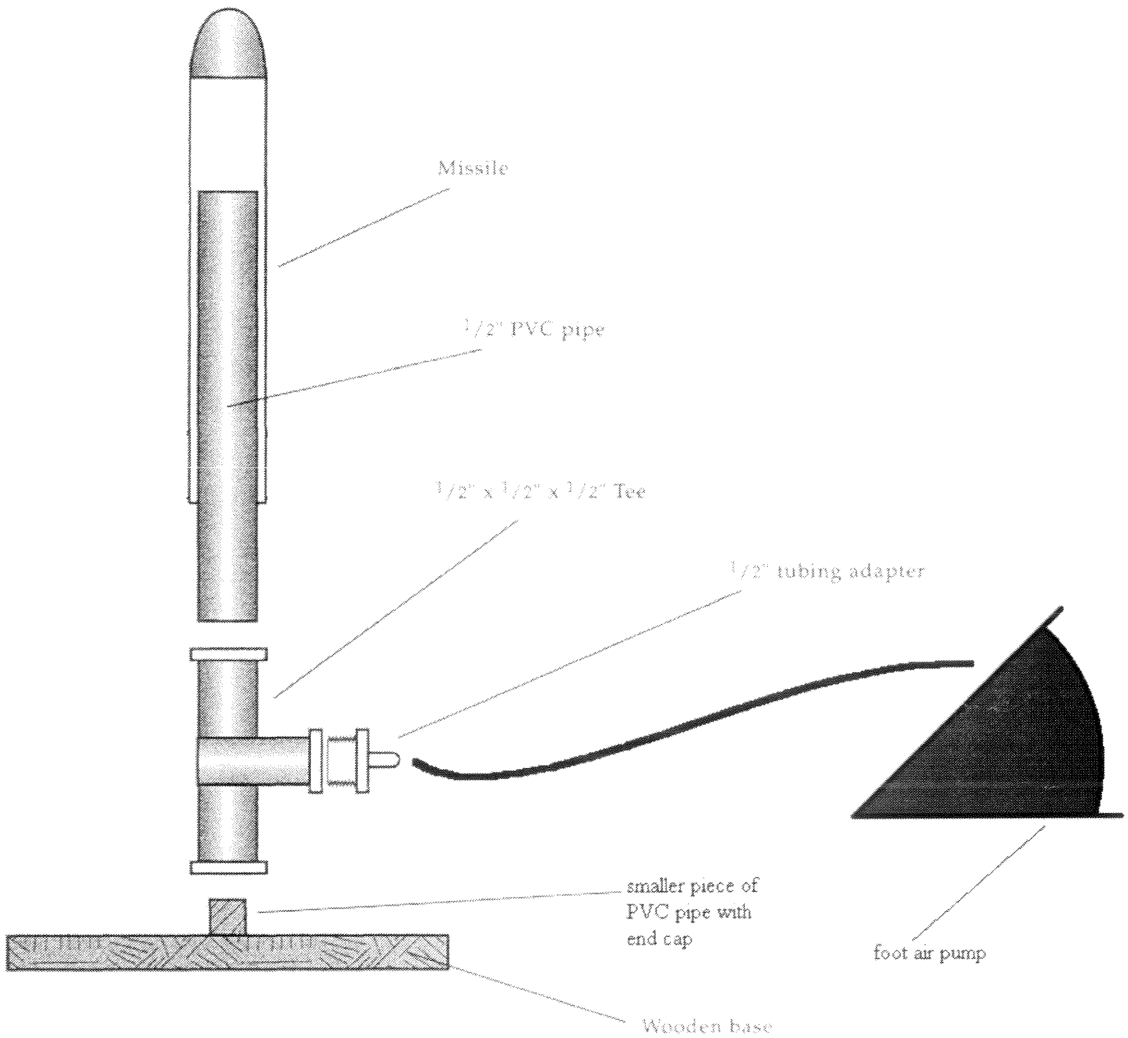


Figure 1 shows the missile assembly.

Figure 2. Front View of Pump Holder

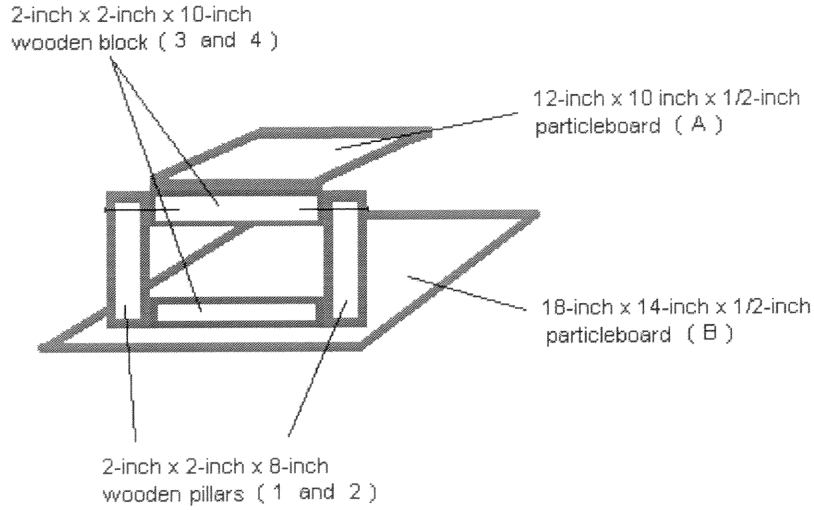


Figure 2 is a diagram of how the foot pump holder is assembled; it shows which pieces are labeled and where each piece goes.

Figure 3. Side View of Pump Holder

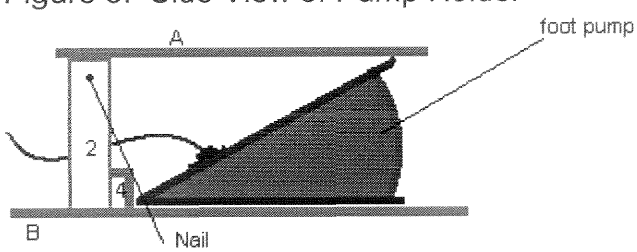


Figure 3 shows a side view of the foot pump holder and how the pump sits in the holder.

DATA AND OBSERVATIONS

Data:

Table 1. Set up of Factors.

Force Applied			*Tube Diameter*		
-	**Standard**	+	-	**Standard**	+
53.96N	84.37 N	133.80 N	Small adapter	Medium adapter	No adapter

Table 1 shows how each trial is set up. The table includes what forces were applied to the pump and which adapter size was used. NOTE: Large adapter size means just using the width of the PVC tubing.

Table 2.

Trial 1			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.397	21.042
3	**(++)**	1.397	19.795
6	**(+-)**	1.016	17.913
4	**STD**	1.321	20.948
5	**(-+)**	1.676	22.429
5	**(--)**	0.635	14.151
7	**STD**	1.245	18.645

Table 3.

Trial 2			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.295	20.348
6	**(++)**	1.473	20.195
2	**(+-)**	0.864	16.380
4	**STD**	1.194	17.223
3	**(-+)**	1.626	22.682
5	**(--)**	0.660	12.895
7	**STD**	1.346	20.551

Table 4.

Trial 3			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.397	19.739
6	**(++)**	1.524	21.299
2	**(+-)**	0.813	15.051
4	**STD**	1.270	19.634
3	**(-+)**	1.727	23.005
5	**(--)**	0.737	14.667
7	**STD**	1.194	18.952

Table 5.

Trial 4			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.194	16.649
3	**(++)**	1.422	20.537
6	**(+-)**	0.889	17.260
4	**STD**	1.245	21.149
5	**(-+)**	1.803	23.093
2	**(--)**	0.559	12.738
7	**STD**	1.372	20.839

Table 6.

Trial 5			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.372	20.396
2	**(++)**	1.422	20.059
6	**(+-)**	0.737	15.146
4	**STD**	1.397	20.502
3	**(-+)**	1.626	25.513
5	**(--)**	0.610	13.509
7	**STD**	1.372	19.123

Table 7.

Trial 6			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.346	19.821
3	**(++)**	1.549	21.002
5	**(+-)**	0.940	16.885
4	**STD**	1.372	19.476
2	**(-+)**	1.676	27.647
6	**(--)**	0.559	12.215
7	**STD**	1.219	19.211

Table 8.

Trial 7			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.270	19.907
2	**(++)**	1.524	20.840
5	**(+-)**	0.864	16.248
4	**STD**	1.422	21.643
3	**(-+)**	1.651	22.702
6	**(--)**	0.559	12.240
7	**STD**	1.245	18.291

Table 9.

Trial 8			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.346	18.267
5	**(++)**	1.473	20.591
6	**(+-)**	0.914	16.791
4	**STD**	1.448	19.860
3	**(-+)**	1.626	23.182
2	**(--)**	0.660	14.201
7	**STD**	1.245	17.514

Table 10.

Trial 9			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.448	20.339
2	**(++)**	1.499	20.129
3	**(+-)**	0.838	15.339
4	**STD**	1.295	18.449
6	**(-+)**	1.676	23.590
5	**(--)**	0.660	13.608
7	**STD**	1.270	18.429

Table 11.

Trial 10			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.372	18.651
3	**(++)**	1.676	22.539
2	**(+-)**	0.914	16.118
4	**STD**	1.397	20.096
5	**(-+)**	1.753	23.337
6	**(--)**	0.559	12.501
7	**STD**	1.397	22.018

Table 12.

Trial 11			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.295	19.579
3	**(++)**	1.372	20.433
6	**(+-)**	0.914	17.028
4	**STD**	1.321	18.156
5	**(-+)**	1.778	19.507
2	**(--)**	0.762	16.065
7	**STD**	1.321	19.978

Table 13.

Trial 12			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.397	19.450
5	**(++)**	1.422	20.025
6	**(+-)**	0.965	17.371
4	**STD**	1.346	18.434
3	**(-+)**	1.829	20.678
2	**(--)**	0.686	16.004
7	**STD**	1.346	21.086

Table 14.

Trial 13			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.219	19.128
3	**(++)**	1.549	21.261
2	**(+-)**	0.914	17.041
4	**STD**	1.346	18.434
5	**(-+)**	1.803	20.025
6	**(--)**	0.610	14.958
7	**STD**	1.270	19.952

Table 15.

Trial 14			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.346	19.783
6	**(++)**	1.270	18.662
2	**(+-)**	0.914	17.322
4	**STD**	1.295	17.808
3	**(-+)**	1.676	21.799
5	**(--)**	0.686	14.866
7	**STD**	1.168	19.854

Table 16.

Trial 15			
Order	Type	Height (m)	Velocity ($^m/_s$)
1	**STD**	1.346	18.695
6	**(++)**	1.295	18.332
2	**(+-)**	0.838	15.947
4	**STD**	1.473	19.570
5	**(-+)**	1.880	21.039
3	**(--)**	0.762	15.070
7	**STD**	1.270	17.433

Tables 2 through 16 show all of the data from our trials. They include the order in which each setup was run, the observed height, and the calculated velocity of each type of run.

Table 17. The High and Low Averages for Height.

	RUNS: HEIGHT (m)			
	(+ +)	(+ -)	(- +)	(- -)
	1.397	1.016	1.676	0.635
	1.524	0.813	1.727	0.737
	1.473	0.864	1.626	0.660
	1.422	0.889	1.803	0.559
	1.422	0.737	1.626	0.610
	1.524	0.864	1.651	0.559
	1.499	0.838	1.676	0.660
	1.549	0.940	1.676	0.559
	1.473	0.914	1.626	0.660
	1.676	0.914	1.753	0.559
	1.372	0.914	1.778	0.762
	1.549	0.914	1.803	0.610
	1.422	0.965	1.829	0.686
	1.270	0.914	1.676	0.686
	1.295	0.838	1.880	0.762
AVERAGE	1.458	0.889	1.720	0.647

Table 17 shows all of the data recorded for the height of the missile in each different setup.

Grand Average: 1.785 meters

Table 18. The High and Low Averages for Velocity.

	RUNS: VELOCITY ($^m/_s$)			
	(+ +)	(+ -)	(- +)	(- -)
	19.795	17.913	22.429	14.151
	21.299	15.051	23.005	14.667
	20.195	16.380	22.682	12.895
	20.537	17.260	23.093	12.738
	20.059	15.146	25.513	13.509
	20.840	16.248	22.702	12.240
	20.129	15.339	23.590	13.608
	21.002	16.885	27.647	12.215
	20.591	16.791	23.182	14.201
	22.539	16.118	23.337	12.501
	20.433	17.028	19.507	16.065
	21.261	17.041	20.025	14.958
	20.025	17.371	20.678	16.004
	18.662	17.322	21.799	14.866
	18.332	15.947	21.039	15.070
AVERAGE	20.380	16.523	22.682	13.979

Table 18 shows all of the data recorded for the velocity of the missile in each different setup.

Grand Average: 18.391$^m/_s$

Observations:

Table 19.

Trials 1-15	We noticed that everything worked fine.
Trials 16-30	The adapter for the small trials was not drilled straight so we needed to redo it. The base that holds the pump broke as well.
Trials 31-45	The Photogates began to have problems reading the missile so they needed to be plugged in differently.
Trials 46-60	The base broke again with approximately 5 trials left so it needed to be fixed.

Table 19 states various observations that we noticed while running our experiment.

Conversions:

Each trial was originally recorded in inches and had to be converted to meters. In order to convert each piece of data to meters we had to multiply it by .0245 meters per inch ($^{m}/_{in}$). For example, one data point measured 40 inches; so, to convert that point to meters, we multiplied it by .0254 and arrived at the answer of 1.016 meters.

(Height in inches) x (.0254) = Height in meters

To convert the kilogram weights into forces, multiply the mass by 9.81 which is the acceleration due to gravity, thus the formula looks like this: F = ma. For example, one of the weights we dropped was 5.5 kg. We multiplied it by 9.81 and got a Newton force of 53.96 Newtons.

(Mass of weight) x (9.81) = Force

DATA ANALYSIS AND INTERPRETATION

We tested the effect of force and tube diameter on the height and velocity of the missile. We had to run two separate 2-factor DOE's. The first set of DOE's tests the effect of the force and tube diameter on the height of the missile; the second set tests the effects of force and tube diameter on the velocity of the missile.

Response Variable: Height of the Missile

Predictor Variable 1: Force applied

Predictor Variable 2: Tube Diameter

Table 20.

45 Standards		
Height (m)	**Height (m)**	**Height (m)**
1.397	1.270	1.346
1.321	1.422	1.448
1.245	1.245	1.245
1.194	1.448	1.219
1.245	1.295	1.346
1.372	1.270	1.270
1.397	1.372	1.397
1.270	1.397	1.346
1.194	1.397	1.346
1.372	1.346	1.295
1.397	1.372	1.346
1.372	1.219	1.168
1.295	1.295	1.346
1.194	1.321	1.473
1.346	1.321	1.270

Table 20 shows each of the 45 standards run for the height of the launched missile.

Figure 4.

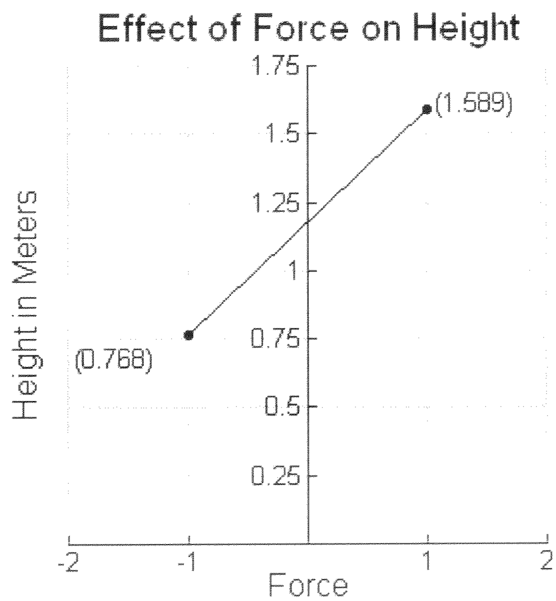


Figure 4 shows the effect of the force applied on missile. The effect of the force on the missile was **.821** meters. On average, as force increases, the height of the missile increases by **.4105** meters. Table 21 shows the calculated average height for the low and high forces used on the foot pump.

Table 21.

Force	
Value (-)	**Value (+)**
0.889	1.720
0.647	1.457
Avg. = 0.768	**Avg. = 1.589**

Table 22.

Tube Diameter	
Value (-)	**Value (+)**
1.720	0.889
0.647	1.457
Avg. = 1.184	**Avg. = 1.173**

Figure 5.

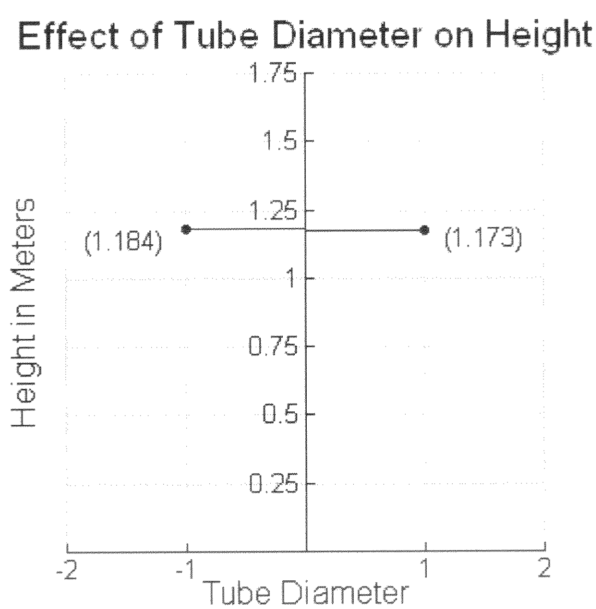


Table 22 shows the calculated average height for the low and high tube diameters. Figure 5 shows the effect of the tube diameter on missile. The effect of the tube diameter on the missile was **-.011** meters. Figure 5 shows that on average, as tube diameter increased the height of the missile decreased by **.0055** meters.

Figure 6.

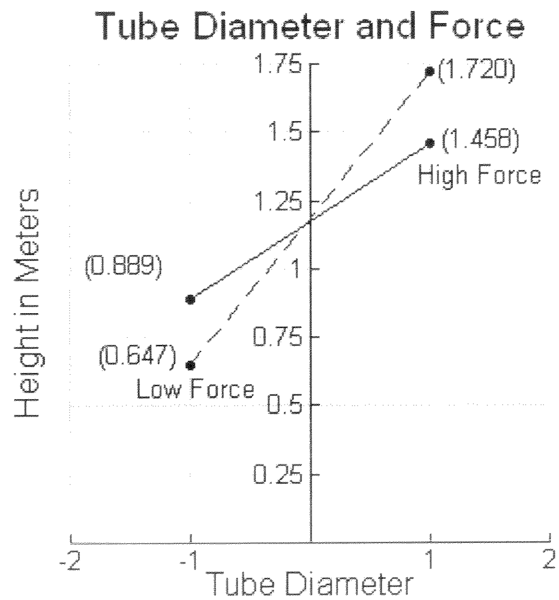


Figure 6 shows the interaction between the force applied and the tube diameter on the effect of the missile height. Table 23 shows the averages of each combined factor.

Table 23.

		(-) Tube Diameter	(+) Tube Diameter
Line segment solid	(+) Force	0.889	1.458
Line segment dotted	(-) Force	0.647	1.720

The slope of the high force line is .2845 and the slope of the low force line is .5365. This gives an effect of -.2520. Because the lines intersected, we can conclude that there was a possible interaction between force and tube diameter on height. The prediction equation is as follows:

Y= 1.178517 + .4105 * Force + .0055 * Tube Diameter + -.1260 * F * TD

Figure 7.

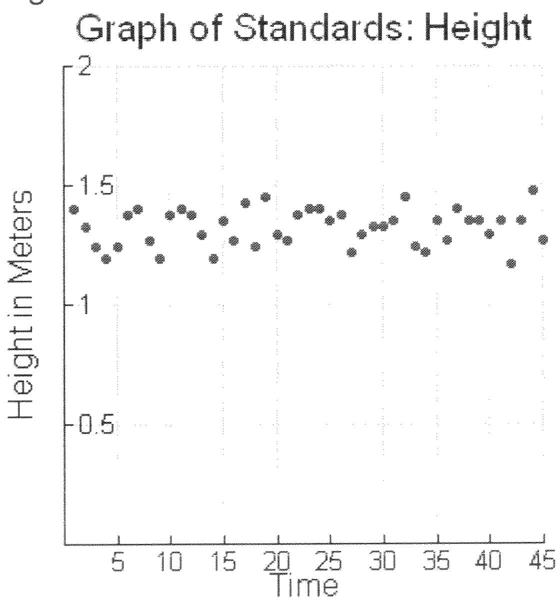


Figure 7 shows the distributions of the standard trials for the height of the missile. Because this graph shows a somewhat linear pattern over time, we could say that the trials could have changed slightly over time but because the line is horizontal, we can conclude that the trials remained consistent.

Response Variable: Velocity of the missile

Predictor Variable 1: Force applied

Predictor Variable 2: Tube Diameter

Table 24.

45 Standards		
Velocity ($^m/_s$)	**Velocity** ($^m/_s$)	**Velocity** ($^m/_s$)
21.042	19.907	18.267
20.948	21.643	19.860
18.645	18.291	17.514
16.649	20.339	19.128
21.149	18.449	18.434
20.839	18.429	19.952
19.739	18.651	19.450
19.634	20.096	18.434
18.952	22.018	21.086
20.396	19.821	19.783
20.502	19.476	17.808
19.123	19.211	19.854
20.348	19.579	18.695
17.223	18.156	19.570
20.551	19.978	17.433

Table 24 shows each of the 45 standards run for the velocity of the launched missile.

Figure 8.

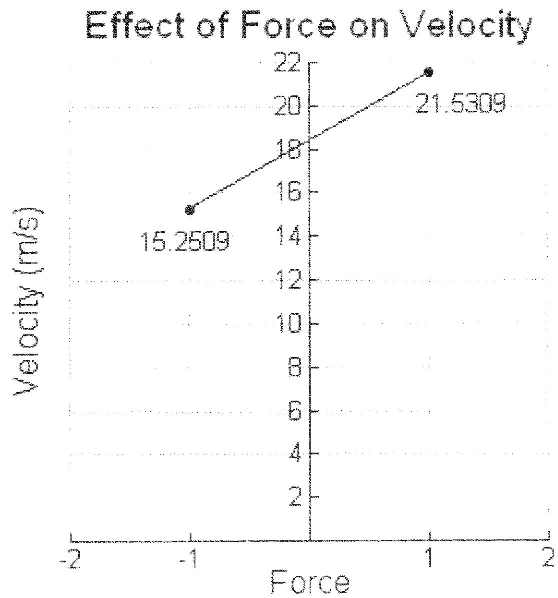


Figure 8 shows the effect of the force applied on the missile. The effect of the force on the missile was **<u>6.2800 $^{m}/_{s}$</u>** and on average, as the force increased the velocity increased by **<u>3.140 $^{m}/_{s}$</u>**. Table 25 shows the calculated averages for the velocity of the missile.

Table 25.

Force	
Value (-)	**Value (+)**
16.523	22.682
13.979	20.380
Avg. = 15.251	**Avg. = 21.531**

Table 26.

Tube Diameter	
Value (-)	**Value (+)**
22.682	16.523
13.979	20.380
Avg. = 18.331	**Avg. = 18.451**

Figure 9.

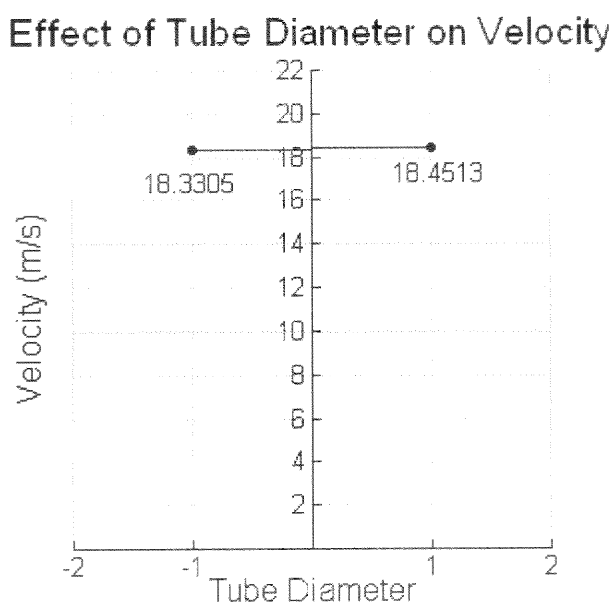


Figure 9 shows the effect of the tube diameter on missile. The effect of the tube diameter on the velocity of the missile was **<u>.1208 $^{m}/_{s}$</u>** while, on average, as the tube diameter increase the velocity of the missile increased by **<u>.0604 $^{m}/_{s}$</u>**. Table 26 shows the calculated averages for the velocity.

Figure 10.

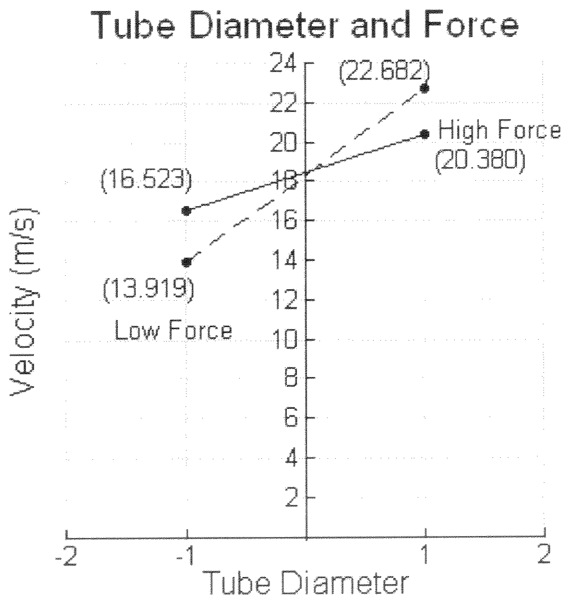


Figure 10 shows the interaction between the force applied and the tube diameter on the effect of the missile's velocity. Table 27 shows the averages of each of the combined factors.

Table 27.

		(-) Tube Diameter	(+) Tube Diameter
Line segment solid	(+) Force	16.523	20.380
Line segment dotted	(-) Force	13.919	22.682

The slope of the high force line is 1.9285 and the slope of the low force line is 4.3815 therefore the effect was –2.423. Because the lines intersect, we can assume there was possibly some sort of interaction between the tube diameter and the force on the velocity of the missile. The prediction equation is as follows:

Y= 18.39092+ 3.14 * Force + .0604 * Tube Diameter + -1.2115 * F * TD

Figure 11.

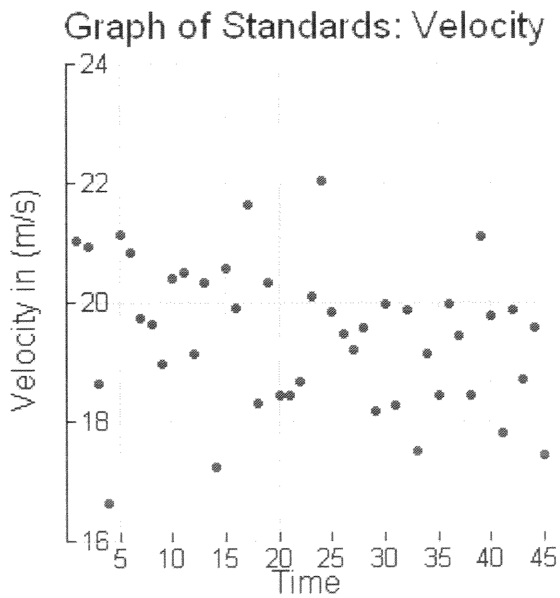


Figure 11 shows a graph of the distributions of the standard trials for the velocity of the missile. Because this graph shows that there is no general pattern over time, we can conclude that the tests are not changing over time.

CONCLUSION

In conclusion, we accept our hypothesis that if we change the diameter of the tube and the force applied to the pump, then the smallest tube diameter and largest force will give the missile the largest velocity and launch the missile the highest in the air. Through experimentation and our statistical analysis, we found that the large force and the smallest tube diameter produced the largest height and velocity. We also determined that there was no interaction between the force that was applied to the pump and the tube diameter. Therefore, the larger the force, the higher and faster the missile went; however, the smaller the tube diameter the higher and faster the missile went, even though it was only a slight change.

From our experiment, we found that there could be many real world applications. One of which is making heavy machinery quieter and less reliant on fossil fuel. One thing people have found is how much quieter pneumatics makes items such as jackhammers.

We also had many sources of error in our experiment. One of which was the pump holder. We did not initially think we would need such an item so therefore we had to build it. The holder itself was not very sturdy either and broke twice. Another source of error was the Photogates. We had to constantly restart trials because the Photogates would not read the missile. Also, one of the adapter holes for the tube diameter was not drilled exactly center so that when the missile was launched it would curve or hit the Photogate, causing us to have to reset up the Photogates and restart the entire run. Another source of error

was that the force was not applied to the same point on the foot pump every time we dropped the force. Although, we tried our best to ensure that it hit at the same point every time, there was no perfect way to make sure this occurred.

Our study could be expanded in many areas. We could use an air compressor instead of a foot pump and change the amount of PSI (pounds per square inch) used to launch the missile. We could have a different way of reading and recording the height that the missile reaches. In addition, we could have a better set up with the Photogates and not have them quite so close to the launcher or spread apart more. Finally, we could use different missiles and see which design would work best and cause the least amount of air resistance.

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